DETUNED RANDALL-SUNDRUM MODEL: RADION STABILIZATION AND SUPERSYMMETRY BREAKING *

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In this talk I describe the low energy effective theory of the (supersymmetric) Randall-Sundrum scenario with arbitrary brane tensions. The distance between the branes is stabilized, at the classical level, by a potential for the radion field. In the supersymmetric case, supersymmetry can be broken by a VEV for the fifth-component of the graviphoton.

1. Introduction

Warped compactifications offer a completely new perspective on the hierarchy problem. In the Randall-Sundrum (RS) scenario [1], five-dimensional AdS space is compactified on an orbifold $S^1/\mathbb{Z}_2$ with two opposite tension branes located at the orbifold fixed points. The ratio between the Planck mass and the electro-weak scale can be explained by the gravitational red-shift of the metric along the fifth-dimension. The hierarchy problem is rephrased in terms of the distance between the branes which is a modulus of the compactification. A stabilization mechanism is necessary.

In this talk I will consider a generalized version of the RS model with "detuned" brane tensions [2]. An intriguing new feature of this scenario is the fact that the brane tensions fix the distance between the branes in the vacuum. I will present the low energy effective action for the radion for arbitrary tensions. I derive the results in the supersymmetric version of the

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model, where the low energy dynamics is controlled by an $N = 1$ supersymmetric $\sigma-$model. The low energy effective action includes a potential for the radion which stabilizes the size of the extra-dimension. I will also argue that in the detuned scenario supersymmetry can be broken spontaneously by a non-trivial Wilson line for the graviphoton. The effective theory in the non-supersymmetric scenario can be easily obtained from the supersymmetric case. The material presented here is based on the papers [3],[4] in collaboration with J. Bagger.

2. The detuned Randall-Sundrum model

The supersymmetric version of the model was constructed by Bagger and Belyaev [5]. The action is given by minimal $5D$ supergravity supplemented by brane actions. Neglecting the Chern-Simons term, the bosonic part of the action is simply

$$\begin{aligned} S_{\rm bulk} &= -\frac{T}{6k}\int d^4x \int_{-\pi}^{\pi} d\phi \sqrt{-G}\Big(\frac{1}{2}R - 6k^2 + \frac{1}{4}F^{MN}F_{MN}\Big) \\ S_{\rm brane} &= -T_0\int d^4x\sqrt{-g_0} - T_\pi \int d^4x \sqrt{-g_\pi}, \end{aligned} \tag{1}$$

where F_{MN} is the field strength of a $U(1)$ gauge field, B_M, called the graviphoton. I work in the orbifold covering space with the branes located at $\phi = 0$ and $\phi = \pi$. Supersymmetry requires the tensions to satisfy the bound $T_{0,\pi} \leq T$ [5]. The full bulk-plus-brane theory is invariant under five-dimensional $N = 2$ supersymmetry in the bulk, restricted to four-dimensional $N = 1$ supersymmetry on the branes. This guarantees that the effective theory is $N = 1$ supersymmetric.

For generic tensions satisfying the bound above, the ground state metric is four-dimensional AdS space warped along the fifth-dimension,

$$ds^2 = F(\phi)^2 g_{mn} dx^m dx^n + r_0^2 d\phi^2. \tag{2}$$

Here the metric g_{mn} is AdS$_4$ with radius L and the warp factor is,

$$F(\phi) = e^{-kr_0|\phi|} + \frac{1}{4k^2L^2} e^{kr_0|\phi|}. \tag{3}$$

The radius L is related to the tensions,

$$\frac{1}{4k^2L^2} = \frac{T - T_0}{T + T_0}. \tag{4}$$

In contrast to the original RS scenario (which corresponds to the choice $T_0 = -T_\pi = T$), the radius r_0 of the extra-dimension is fixed,

$$2\pi k r_0 = \log \frac{(T+T_0)(T+T_\pi)}{(T-T_0)(T-T_\pi)}. \tag{5}$$

However the VEV of B_5 is not determined; it is the only modulus of the compactification.

3. Supersymmetric effective action

The general form of the effective action is determined by the symmetries of the five-dimensional theory up to four free constants.

The bosonic low energy effective action includes the fluctuations of the four-dimensional metric g_{mn}, together with the light modes of G_{55} and B_5. The scalar associated with G_{55} can be identified as the proper distance between the branes, the radion field. The other scalar is obviously the zero mode of B_5. In the supersymmetric effective theory the two scalars join with the fifth-component of the gravitino to form a chiral multiplet. The zero mode of B_5 must be massless. The Kaluza-Klein reduction fixes the mass of the radion to be $4/L^2$. This is precisely the value of the mass required by the representations of supersymmetry in AdS$_4$.

The effective action is $N = 1$ supersymmetric, so it is determined by a Kähler potential K and a superpotential P. The bosonic part of the action (setting $M_4 = 1$) takes the form

$$S_{\text{eff}} = -\int d^4x\sqrt{-g}\Big[\frac{1}{2}R + K_{\tau\overline{\tau}}g^{mn}\partial_m\tau\partial_n\overline{\tau} + e^K(K^{\tau\overline{\tau}}D_\tau P D_{\overline{\tau}}\overline{P} - 3P\overline{P})\Big], \tag{6}$$

where τ is the lowest component of the radion superfield, and $D_\tau P = \partial_\tau P + K_\tau P$. It can be shown that $\tau = r + ib$ where r is the radion field and b is the zero mode of B_5.

To determine K and P, one can observe that the bosonic part of the action (1) is invariant under a shift of B_5. This implies that, up to a Kähler transformation, K is a function of $\tau + \overline{\tau}$ (it does not contain b). By the same argument, the potential in (6) is also a function of $\tau + \overline{\tau}$. Since the superpotential is a holomorphic function of τ, this condition imply an infinite number of constraints on K and P. We found that, in an AdS$_4$

ground state, the most general solution of these constraints is[a]

$$K(\tau,\overline{\tau}) = -3\log[1 - c^2\, e^{-a(\tau+\overline{\tau})}]$$
$$P(\tau) = p_1 + p_2\, e^{-3a\tau}, \tag{7}$$

where p_1, $p_2 \in \mathbb{C}$ and c, $a \in \mathbb{R}$ are undetermined constants.

With a simple change of variables one can recognize that this is the Kähler potential of no-scale supergravity. In fact the superpotential is the generalization to AdS_4 of the constant superpotential of ordinary no-scale supergravity [4].

4. Results

The unknown constants in (7) can be determined performing the Kaluza-Klein reduction of the bosonic fields. This requires a careful treatment of the tadpoles of the light fields with the heavy fields [4]. One finds that the Kähler potential and the superpotential for the radion are given by

$$K(\tau,\overline{\tau}) = -3\log\left[1 - e^{-\pi k(\tau+\overline{\tau})}\right]$$
$$P(\tau) = \frac{k}{L}\sqrt{\frac{6}{T}}\left(1 - e^{\pi k r_0} e^{-3\pi k\tau}\right). \tag{8}$$

The bosonic part of the action is then

$$S_{\mathrm{eff}} = -\int d^4x \Big[\frac{M_4^2}{2}R + 3k^2\pi^2\, M_4^2\, \frac{e^{-k\pi(\tau+\overline{\tau})}}{(1-e^{-k\pi(\tau+\overline{\tau})})^2} g^{mn}\partial_m\tau\partial_n\overline{\tau} + V(\tau,\overline{\tau})\Big], \tag{9}$$

where I have inserted the four-dimensional Planck mass M_4. The scalar potential is

$$V(\tau,\overline{\tau}) = -\frac{3\, M_4^2\,(1-e^{-2k\pi r_0})}{L^2}\left[\frac{1-e^{-2k\pi(\tau+\overline{\tau}-r_0)}}{(1-e^{-k\pi(\tau+\overline{\tau})})^2}\right]. \tag{10}$$

As required, the potential is independent of b. The ground state is AdS_4; the potential stabilizes the radius of the extra-dimension (at $r = r_0$), while b remains, at the classical level, a modulus of the compactification.

The purely gravitational case can be obtained by setting $b = 0$ in (9). For the case $T_{0,\pi} \geq T$ the $4D$ ground state is de-Sitter space and the $5D$ theory cannot be supersymmetrized. The effective action can be still

[a]This holds for $m_r^2 = 4/L^2$

obtained from the supersymmetric result (9) replacing $L \to iL$. The ground state is unstable in this case.

From the $5D$ point of view one can show that when b has a VEV (corresponding to a non-trivial Wilson line of the graviphoton), the Killing spinor equations have no solutions; supersymmetry is spontaneously broken [3] (see also [6]. For a similar effect in flat space see [7] and references therein). This effect however vanishes when the tensions are tuned. In the effective theory, unbroken supersymmetry requires that $D_\tau P$ vanish, when evaluated at the minimum of the potential. It is easy to check using (8) that supersymmetry is broken when $b \neq 2n/(3k)$, for n integer. This mechanism of supersymmetry breaking is the AdS_4 analog of the one in no-scale supergravity.

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